

# Freezing of Gait in Parkinson's Disease: The Impact of Dual-Tasking and Turning

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**Abstract:** Background: Turning is the most important trigger for freezing of gait (FOG) in Parkinson's disease (PD), and dual-tasking has been suggested to influence FOG as well. Objective: To understand the effects of dual tasking and turning on FOG. Methods: 14 Freezers and 14 non-freezers matched for disease severity and 14 age-matched controls were asked to turn 180° and 360° with and without a cognitive dual-task during the off-period of the medication cycle. Total number of steps, duration, cadence, freezing-frequency, and secondary-task performance were measured. Results: Seven freezers froze during the protocol. Freezing occurred in 37.5% of trials during 180° turning compared to 0% during straight-line walking ( $X^2 = 10.44$ ,  $p < 0.01$ ). The occurrence of FOG increased during 360° when also a dual-task was added ( $X^2 = 4.23$ ,  $p = 0.04$ ). Freezers took significantly more steps and were

slower than controls in all conditions. The presence of a dual-task increased these differences. Cadence increased significantly for freezers during 360° and 180° compared to straight-line walking. In contrast, cadence was decreased during turning in controls and non-freezers. During straight-line walking, only freezers made errors in the secondary task. Controls increased their error-rate during 180° turning, whereas freezers deteriorated their secondary task performance during 360°. Conclusions: 360° turning in combination with a dual-task is the most important trigger for freezing. During turning, non-freezers and controls decreased their cadence whereas freezers increased it, which may be related to FOG. Freezers adopted a posture second strategy in contrast to non-freezers when confronted with a dual task. © 2010 Movement Disorder Society

**Key words:** freezing of gait; turning; dual-task

Freezing of gait (FOG) is an episodic inability to generate effective stepping<sup>1</sup> and is often described by patients as if their feet are glued to the floor.<sup>2</sup> Almost 50% of patients with Parkinson's disease (PD) experience FOG at least twice a month and in the more advanced stages even 80% may suffer from this symptom.<sup>3</sup> 26% of falls were found to be related to freezing,<sup>4</sup> and this may contribute to the fact that FOG has a highly significant impact on patients' quality of life.

It has been shown that FOG occurs most frequently during turning and even more so when the turning angle increases to 360°.<sup>5</sup> While turning difficulties appear associated with freezing,<sup>6</sup> only limited studies have been conducted to characterize these difficulties. In a previous study from our group, we found that freezers spontaneously made a larger turning-arc than non-freezers.<sup>7</sup> Mak et al.<sup>8</sup> showed that, compared to controls, freezers achieved only 75% of the required turning angle and needed more time to complete a turn. These problems were relatively independent of the turning angle (30° turn vs. 60°).

Not only turning, but also dual-tasking (DT) or other circumstances, which load the cognitive system, have been suggested to induce freezing.<sup>9,10</sup> However, the actual link between FOG and DT has never been demonstrated before.

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Dual- and multitask performance is substantially compromised in PD, showing exaggerated slowing and increased dysrhythmicity of gait.<sup>11</sup> As for its relationship with freezing, it was found that walking in freezers was substantially more influenced by a verbal fluency task than in non-freezers.<sup>12</sup> Hackney and Earhart<sup>13</sup> showed that, gait performance of freezers was more affected by the DT during walking backwards, although the secondary-task performance was comparable in both groups. Overall, freezers seemed to prioritize the DT instead of the walking.

This study will investigate the effects of both DT and turning on FOG, separately and together. Based on previous work,<sup>13</sup> we hypothesized that turning will have a higher impact on freezing and the spatiotemporal parameters of gait than DT. We also expect that a combination of both factors will increase the occurrence of freezing and will have a larger impact on the gait pattern of freezers than of non-freezers.

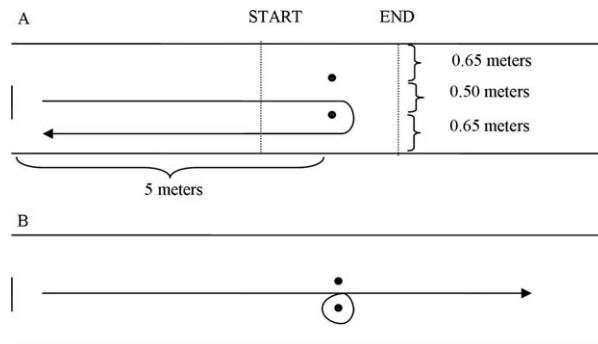
## SUBJECTS AND METHODS

### Subjects

Twenty-eight patients diagnosed with idiopathic PD in stage II or III of Hoehn and Yahr<sup>14</sup> (H&Y) and 14 healthy age-matched subjects were recruited. The study was approved by the local ethics committee, and all subjects gave written informed consent. Patients were recruited in the Movement Disorders Clinic of the University Hospital Leuven. The following inclusion criteria were used: (1) ability to walk 10 m repeatedly during the off-phase, (2) no dementia, as measured by the Mini-Mental State Examination (MMSE > 24),<sup>15</sup> (3) no Deep Brain Stimulation, and (4) no comorbidity limiting gait. Furthermore, equal numbers of patients were recruited with and without FOG as ascertained by the first item of the revised freezing of gait questionnaire (NFOGQ).<sup>16</sup> "Freezers" were defined as patients who had experienced freezing at least once during the past month (NFOGQ item 1  $\geq$  1). When a patient was classified in the non-freezer group by the NFOGQ, but froze during our test protocol ( $N = 1$ ), he or she was reallocated to the freezer group. The two patient subgroups were matched for disease severity based on the Unified Parkinson Disease Rating Scale motor part (UPDRS III)<sup>17</sup> and H&Y stage. Furthermore, the Scopa-COG<sup>18</sup> was examined to compare the cognitive deficits considered specific to PD between the different groups.

### Test Protocol

Patients were asked to omit their morning dose of medication. Tests took place early in the morning, 12 to



**FIG. 1.** Walkway. Two retroreflective markers (●) were placed in the middle of the walkway. Data collection started 1 m in front (START) and stopped 1 m after the markers (END). A. Trajectory during 180° turning; B. trajectory during 360° turning.

15 h after the last medication intake (off-period). The protocol required subjects to walk along a walkway of 5 m between two retroreflective markers placed 0.5 m away from each other (Fig. 1). They were asked to either (1) continue to walk straight ahead or (2) make a left or (3) right turn of varying angles (180° and 360°) around the marker before walking further. The markers were small and unobtrusive, and their position was chosen so that no space limitation was suggested, and that subjects were prevented from enlarging their turning cycle to standardize turning performance (see Fig. 1). The five experimental conditions (straight, 180°-right, 180°-left, 360°-right, and 360°-left) were offered randomly and performed alternatively in a block without and with a verbal cognitive DT (the color classification task<sup>19,20</sup>) till three trials for each condition were collected. The choice for the color-classification task was based on extensive pilot work. It was chosen for its adequacy in terms of its difficulty level for various patients and the possibility to vary the load without increasing the level of difficulty. It consisted of, two colors presented verbally by a prerecorded audiotape in a random order at 2-second intervals. The subjects were instructed to answer "yes" or "no" to the different colors, whereas continuing to walk or turn without explicit task prioritization. Colors and answering code were changed every trial to ensure that performance did not habituate. Errors in secondary-task performance were immediately recorded by the tester. Errors included code-reversals and missing responses. No errors were found in secondary task performance while sitting. Resting periods were provided at regular intervals to avoid fatigue.

### Apparatus

An eight camera VICON data capturing system (Vicon Motion Systems, Workstation 612) was positioned around

a 10 m walkway. Retroreflective markers (14 mm in diameter) were placed on the anatomical bony landmarks according to the standardized procedure of the gait laboratory (full body plug-in-gait marker configuration).

### Data Processing

The data processing of straight, 180°, and 360° turning started from the initial foot contact passing an invisible line (measured with the VICON workstation), 1 m in front of the reflective markers placed on the floor, till the first foot crossed an invisible line 1 m after the markers. This meant that during the turning conditions the data represented the actual turning action, including the straight-line steps just before and after the turn within the spatial confounds of 2 m.

The following parameters were calculated:

1. Total number of steps between the start and endpoint of the data processing.
2. Total duration, the time between the start and endpoint of the data processing.
3. Cadence was inferred indirectly from the total number of steps and total duration, allowing analysis of interaction effects between group, dual tasking and turning (as a 3-way repeated factor).
4. Freezing trials: FOG was defined according to the recently published definition as an episode of inability to generate effective stepping often leading to a halt<sup>1</sup> based on visual analysis of the 3D images using Vicon workstation software. Two raters with a clinical background, blinded for NFOGQ-score visually detected all trials in which freezing episodes occurred independently from each other. The interrater reliability of this procedure was 0.95 ( $p = 0.99$ ) calculated by Cohen's KAPPA statistic. When no consensus was reached, the opinion of a third independent researcher was adopted.
5. Secondary-task performance: Errors were immediately recorded by the tester. Number of errors was calculated as a percentage of the total amount of answers given by the subject in that trial. The dual-task was first tested during sitting to ensure that the answering task was clear.

Data were calculated as an average of the three trials. For this analysis, data on turning to the left and right were pooled.

### Statistical Analysis

Group differences of clinical characteristics were analyzed with an analysis of variance (ANOVA) for the

MMSE-score, Scopa-COG, and age. Disease duration, UPDRS, and H&Y were analyzed with the Student's t-test.

Occurrence of FOG was analyzed using a Pearson's chi-square ( $X^2$ ) test. When FOG occurred between the start and endpoint of the data processing, the trial was excluded for further analysis. Total number of steps and duration of gait were analyzed for the different turning conditions (straight, 180°, and 360°) using a repeated-measures ANOVA with one fixed factor (group) and one repeated factor (presence of a dual-task). When significant differences were found, post-hoc Fisher LSD tests were performed.

Cadence was analyzed using 3\*2\*3 repeated measures ANOVA with one fixed factor (group) and two repeated factors (task condition and turning condition). When significant differences were found, post-hoc Fisher LSD tests were performed.

Because of the skewed distribution, group differences in secondary-task performance were tested non-parametrically with the Kruskal-Wallis tests for the three different turning conditions separately. Differences between the turning conditions were tested with the Friedman test for each group separately.

A correlation analysis was conducted using the Spearman rho statistic to explore the relationship between the actual occurrence of FOG (number of freezing trials) and the NFOG-score as dependent variables and the following cognitive outcomes: SCOPA-COG total score and subscores, secondary-task performance, and dual-task interference (single-dual task cadence expressed as a percentage of single task cadence). Statistical analysis was performed using Statistica (version 9.0). Significance levels for all tests were set at  $\alpha = 0.05$ .

## RESULTS

### Subjects

Table 1 shows the clinical characteristics of the three groups. Freezers and non-freezers were comparable for disease duration, UPDRS III, and H&Y. No significant differences in age and leg length were found between the three groups. Freezers had a significantly worse score on the cognitive tests than controls and non-freezers, especially on the attention part of the SCOPA-COG (see Table 1), but the average score of the MMSE was well above 24.

### Freezing Occurrence

Freezing was provoked in 10 out of 14 freezers during the test period, but only seven froze during the trials, which were visible for the cameras. This group of seven freezers froze in 16.1% of the trials. Freezing occurred in 37.5% of trials in which these seven

**TABLE 1.** Subject characteristics: mean (SD) measured during ON-phase of the medication cycle

	Controls	Non-freezers	Freezers
Age (years)	65.2 (6.8)	66.7 (7.4)	68.6 (7.4)
Leg length (cm)	90.1 (4.9)	88.9 (6.5)	88.5 (4.3)
MMSE	29.1 (1.3)**	28.7 (1.2)*	27.7 (1.1)
Scopa-COG total	30.9 (6.3)**	30.3 (4.0)*	26.1 (5.1)
Memory part	12.4 (4.3)	11.9 (2.9)	9.5 (3.6)
Attention	3.7 (0.8)**	3.9 (0.4)*	3.1 (0.8)
Executive function	10.3 (1.8)	10.4 (1.3)	9.4 (2.2)
Visuospatial functions	4.5 (0.7)	4.2 (0.9)	4.1 (0.7)
Disease duration (years)		7.8 (4.8)	9.0 (4.8)
UPDRS III		34.4 (9.9)	37.9 (14.0)
H&Y		2.4 (0.3)	2.5 (0.5)

\*Freezers and non-freezers significantly different at  $P < 0.05$  (ANOVA).

\*\*Freezers and controls significantly different at  $P < 0.05$  (ANOVA).

patients were asked to turn  $180^\circ$  (15 out of 40  $180^\circ$  turning-trials) compared to zero trials during straight-line walking (37.5% vs 0%,  $X^2 = 10.44$ ,  $p < 0.01$ ). The degree of turning ( $180^\circ$  vs  $360^\circ$ ) made no impact during single task conditions (see Table 2). On the contrary, during dual-task trials a larger turning-degree ( $180^\circ$ – $360^\circ$ ) increased the amount of freezing (37.5% vs 61.1% of the trials,  $X^2 = 4.23$ ,  $p = 0.04$ ). Interestingly, no correlation was found between NFOGQ-scores, dual-task interference, and the occurrence of actual freezing during the protocol.

The DT had no significant effect on FOG during straight-line walking and  $180^\circ$  turning (see Table 2). But in the more severe turning task ( $360^\circ$ ), the number of freezing trials almost doubled when a dual-task was added (61.1% vs 31.6%,  $X^2 = 6.49$ ,  $p = 0.01$ ). This corresponds with an absolute risk increase (ARI) of 29.5%.

### Step Parameters–Loading the Motor System

During 2 m straight-line walking, freezers already walked with significantly more steps (4.5 vs 3.33,  $p = 0.03$ ) and a longer duration (2.36s vs 1.84s,  $p = 0.04$ ) than controls. Comparable results were found during  $180^\circ$  turning, but when freezers turned  $360^\circ$ , they walked even more slowly and with more steps than controls ( $p_{\text{duration}} < 0.01$  and  $p_{\text{steps}} < 0.01$ ) and non-freezers ( $p_{\text{duration}} = 0.02$  and  $p_{\text{steps}} = 0.04$ ) (see Table 3).

### Step Parameters–Loading the Cognitive System

#### Effect of DT on Gait

The interaction of group by condition (dual-task) for total number of steps was significant for normal gait,  $180^\circ$

and  $360^\circ$  turning ( $p = 0.045$ ,  $p < 0.01$  and  $p < 0.001$ , respectively), which means that only freezers needed more steps in the presence of a dual-task compared to walking without a dual-task in all these conditions (see Table 3). Comparable results were found for total duration during normal gait and  $180^\circ$  turning ( $p = 0.015$  and  $p = 0.025$ , respectively), but during  $360^\circ$  turning, only a main effect of DT was found ( $p = 0.03$ ) indicating that trials with DT, took longer than those without DT for all groups.

### Secondary Task Performance

Figure 2 visualizes the error scores of the secondary task of freezers, non-freezers, and controls during the three different turning conditions. During straight-line walking, freezers had significantly ( $p = 0.004$ ) more errors than non-freezers and controls (2.82% vs. 0.00% and 0.00%,  $P < 0.01$ ). No group differences were found when turning  $180^\circ$ . When the turning-angle further increased, only freezers deteriorated their secondary task performance and made significantly more errors compared to  $180^\circ$  and straight-line walking (6.27% vs. 1.78% and 1.21%,  $P = 0.05$  and  $P = 0.04$ ). Therefore, group differences were significant during  $360^\circ$  (6.27% in freezers vs. 0.92% and 1.02% in non-freezers and controls, respectively,  $P = 0.022$  and  $P = 0.025$ ).

To complete the understanding of cognitive loading on FOG, we undertook correlational analysis in the freezer group. Only the secondary-task performance during  $360^\circ$  turning was negatively correlated with the memory part of the SCOPA-COG ( $R = -0.55$ ,  $P = 0.04$ ). When freezers and non-freezers were both included, a moderate correlation ( $R = -0.38$ ,  $P < 0.05$ ) was found between cognition (measured by the total SCOPA-COG) and the NFOGQ-score but not with any performance measures during the gait tests.

### Step-Parameters: Interaction of Loading the Motor and Cognitive System

Cadence was calculated to check interactions between group, turning, and dual-task conditions. Although this result showed a trend ( $p = 0.08$ ), we still explored this

**TABLE 2.** Occurrence of freezing

	Straight	$180^\circ$	$360^\circ$
Single task	0%	37.5% [21.4–53.6]	31.6% [16.1–47.1]
Dual task	5% [0–12.3]	37.5% [21.4–53.6]	61.1% [44.9–77.4]

Percentage of trials calculated from the total amount of trials for each separate condition in which freezing occurred (from the seven freezers who froze during the protocol) and 95% confidence intervals in brackets [ ].



**TABLE 3.** Total steps, duration and cadence (mean  $\pm$  SD) for controls, non-freezers and freezers during straight line walking, 180°, and 360° turning with and without dual-task

	Controls		Non-freezers		Freezers	
	Single task	Dual task	Single task	Dual task	Single task	Dual task
<b>Steps</b>						
Straight	3.33 $\pm$ 0.45	3.31 $\pm$ 0.42	3.83 $\pm$ 0.21	4.10 $\pm$ 0.26	4.50 $\pm$ 0.36	5.62 $\pm$ 0.54
180°	5.82 $\pm$ 0.80	5.77 $\pm$ 1.01	7.14 $\pm$ 0.44	7.08 $\pm$ 0.43	9.76 $\pm$ 1.07	11.36 $\pm$ 1.50
360°	9.36 $\pm$ 1.12	9.55 $\pm$ 1.49	11.62 $\pm$ 0.72	11.83 $\pm$ 0.71	16.89 $\pm$ 1.70	19.11 $\pm$ 2.21
<b>Duration (sec)</b>						
Straight	1.84 $\pm$ 0.31	1.83 $\pm$ 0.25	2.11 $\pm$ 0.13	2.31 $\pm$ 0.16	2.36 $\pm$ 0.15	2.91 $\pm$ 0.20
180°	3.35 $\pm$ 0.50	3.29 $\pm$ 0.71	4.10 $\pm$ 0.25	4.13 $\pm$ 0.27	4.92 $\pm$ 0.41	5.57 $\pm$ 0.66
360°	5.37 $\pm$ 0.71	5.45 $\pm$ 1.07	6.59 $\pm$ 0.42	6.80 $\pm$ 0.44	8.38 $\pm$ 0.71	9.23 $\pm$ 1.09
<b>Cadence (steps/min)</b>						
Straight	109.11 $\pm$ 6.65	108.94 $\pm$ 7.95	109.24 $\pm$ 3.34	107.16 $\pm$ 5.67	113.93 $\pm$ 11.05	114.62 $\pm$ 16.70
180°	104.62 $\pm$ 8.66	106.13 $\pm$ 9.07	104.75 $\pm$ 5.97	103.48 $\pm$ 6.09	117.64 $\pm$ 18.84	121.52 $\pm$ 22.21
360°	105.01 $\pm$ 8.63	106.03 $\pm$ 9.29	106.27 $\pm$ 8.54	105.14 $\pm$ 8.76	119.93 $\pm$ 17.28	125.46 $\pm$ 29.20

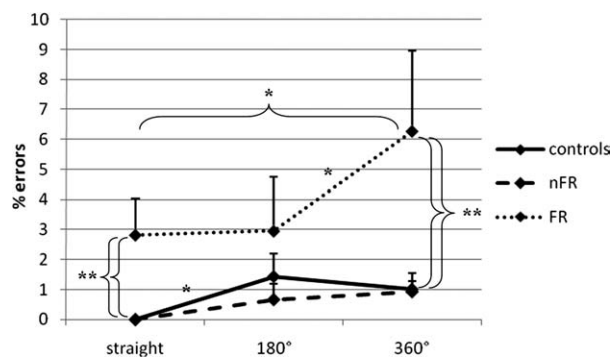
result to get a broader idea on the effect of DT. A post hoc analyses revealed that, apparently only freezers increased their cadence during DT in 360° turning (125.5 steps/min vs. 119.9,  $P < 0.01$ ) whereas non-freezers showed the opposite pattern.

A turn\*group interaction effect ( $P < 0.01$ ) was also found. Post hoc analysis showed that cadence increased significantly for freezers during 360° and 180° compared to straight-line walking (see Fig. 3 and Table 3). On the contrary, cadence was decreased during turning in controls (105.5 steps/min and 105.4 vs. 109,  $P = 0.06$  and  $P = 0.05$ ) and non-freezers (104.1 steps/min during 180° turning vs. 108.2 during straight-line walking,  $P = 0.03$ ).

In addition, the interaction of DT\*turn for cadence was significant ( $P = 0.03$ ). Post hoc analysis showed that the cadence during 360° turning increased in the presence of a dual-task (111.7 steps/min vs. 109.9,  $P = 0.01$ ).

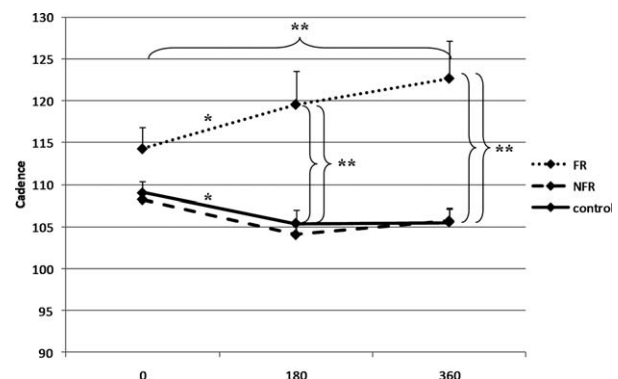
## DISCUSSION

This is the first study that manipulated the effect of turning and DT in patients with and without FOG dur-

**FIG. 2.** Secondary-task performance as a percentage of errors and SEM for controls, freezers (FR), and non-freezers (nFR). \* $P < 0.05$  and \*\* $P < 0.01$ .

ing the off-phase of the medication cycle, to unravel the interaction between these factors, and the occurrence of actual FOG-episodes. Unlike in previous research,<sup>5</sup> FOG did not seem to be significantly influenced by the turning degree alone. Only when a cognitive load was added, freezing was provoked to a much greater degree by a larger turn. Our results, therefore, underscore the fact that DT and turning 360° simultaneously approves a highly freezing triggering condition. As previous studies reported difficulties to provoke FOG-episodes in a standardized laboratory,<sup>21</sup> this finding is of high interest for researchers in this field. Importantly, actual freezing frequency in off was not predicted by the NFOG-score. This may be because the NFOG-score represents daily life freezing in both on and off conditions, which does not necessarily correspond with behavior in an experimental setting.

Although freezers had a significantly worse score on the cognitive tests than controls and non-freezers, no correlations were found between actual FOG-trials and cognition. This is in contrast with recent work,<sup>22</sup> which

**FIG. 3.** Cadence in steps/min and SEM during straight line walking, 180° and 360° turning, for freezers (FR), non-freezers (nFR) and controls. Turn\*group interaction effect. \* $P < 0.05$  and \*\* $P < 0.01$ .

suggested that FOG is possibly associated with an exaggerated executive dysfunction and particularly with a highly deficient shifting ability as a mechanism for triggering FOG.<sup>23</sup> The first mentioned study included test results of both non-freezers and freezers in the analysis. This may be the reason why we could not replicate these findings. Another explanation is the unpredictable occurrence of FOG-episodes on a day-to-day basis, leading to a lack of correlation between the NFOG-score and actual FOG.

The fact that, only during intensive motor loading (360° turning), a significant effect of DT on FOG and cadence was found, and the absence of an association between actual freezing and cognitive impairment suggests that, turning is a more important trigger for freezing than DT.

Freezers seemed to have a specific turning problem in addition to the bradykinesia, already seen in non-freezers, as this data indicated that freezers reacted atypically to turning. While non-freezers and controls decreased their cadence during turning, freezers appeared to increase their cadence. These findings cannot be ascribed to age or disease severity, as groups were matched successfully. A previous study from our group, comparing patients in the on-phase and not restricting the turning arc of patients experimentally, did not show this deficit.<sup>24</sup>

Earlier work examining the pre-freezing steps in more detail, found a decelerated gait, small steps, and a trend of a progressively increasing cadence just before FOG.<sup>25</sup> Therefore, freezing was suggested to be associated with the inability of generating step amplitude, while maintaining a steady rhythm of gait. Chee et al.<sup>26</sup> confirmed that reducing step length induced a sequence effect in freezers, and this increased the occurrence of FOG. Comparable results were found in this study, where freezers had a much higher cadence in the freezing triggering condition (360° + dual-task).

Plotnik et al.<sup>27</sup> pointed to the fact that freezers have already more gait asymmetry than non-freezers irrespective of the most affected side. They speculated that, FOG might be related to asymmetric gait performance and reduced bilateral motor coordination. During turning, the step length of the inner leg decreases, whereas the outer leg continues the ongoing movement, inducing asymmetry.<sup>28</sup> The center of mass deviates to the inner leg to provide the support function, whereas the outer leg completes the turning function. This increasing demand on bilateral coordination during turning might explain the freezing-triggering characteristics of turning. However, further research into the exact biomechanical factors, which may pro-

voke turning problems in freezers, is required and currently undertaken.

In the study of Hackney and Earhart,<sup>13</sup> freezers had no more errors in the secondary task performance than non-freezers. In this study, however, freezers performed significantly worse on the cognitive dual-task during straight-line walking than non-freezers and controls. Freezers and non-freezers were not matched for MMSE and SCOPA-COG, which may explain this difference. Also, the dual task load may be a crucial factor in explaining the discrepancy with previous study.

Bloem et al.<sup>29</sup> suggested that prioritization in DT differs between patients with PD and age-matched controls, whereas controls increased their attention on gait performance, sacrificing their cognitive task (posture first strategy), patients with PD, divided their attention equally between both tasks, resulting in a higher fall risk (posture second strategy). The results of this study support a further distinction between freezers and non-freezers. As in earlier work,<sup>12</sup> only freezers needed more steps in the presence of a dual-task compared to walking without a dual-task in all conditions. In addition, we found that freezers performed significantly worse on the secondary-task than controls and non-freezers, probably due to more pronounced cognitive decline. This difference became even more distinct during the 360° turn, when the secondary task performance collapsed. It seemed that freezers started to adjust their total steps and turn duration first and showed an effect on their secondary-task performance when further increasing the task complexity, indicating a “posture second” strategy. In contrast, controls showed their first adjustments to the increasing task complexity (turning) by a mild deterioration of the secondary task followed by a decline in gait performance, that is, a posture first strategy. Non-freezers’ adjustment strategies were most similar to controls. This highlights some important differences between freezers and non-freezers and argues for the presence of distinctly different compensatory motor responses.

Verghese et al.<sup>30</sup> also found in the “walking while talking”-task that elderly people who focused their attention on gait, whereas DT could normalize their gait without a deterioration of the secondary task. Comparable results were seen in patients with PD.<sup>31,32</sup> Baker et al.<sup>32</sup> suggested a combination of an attentional strategy with an auditory cue to optimize dual task gait in patients with executive dysfunction or in situations with a higher attentional demand. Based on the results of this study, we recommend different learning strategies to cope with DT in freezers and non-freezers, emphasizing allocation of attention to the maintenance of walking.

Some limitations in this study must be acknowledged. Although patients were tested during the off-period, and turning and DT (two freezing-triggering conditions) were combined, still the occurrence of FOG-episodes was limited. Although the color-classification task was feasible and provided an adequate difficulty level, the measurement of task performance by means of the error-scoring was limited. In addition, and unlike the motor loading, no 3-level task difficulty could be tested in the current protocol within the limits of fatigue.

In conclusion, we found that the most pronounced triggering condition for freezing was performing a 360° turn in combination with a dual-task. During turning, non-freezers and controls decreased their cadence, whereas freezers increased it, which may be related to FOG. Our data suggest that freezers adopted a posture second strategy in contrast to non-freezers, when confronted with a dual task. Further research into the asymmetry of turning and the possible link with freezing should be undertaken.

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